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ES and H manual

Environment, Safety, and Health

Volume II

Part 16: Electrical

16.1
Electrical Safety

(Formerly H&SM Chapter 23)

Recommended for approval by the ES&H Working Group

Approved by: Robert W. Kuckuck
Deputy Director for Operations

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16.1

Electrical Safety*

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* Minor revision

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Electrical Safety

1.0 Introduction

This document contains general requirements for all Laboratory work involving the use of electrical equipment and systems. Appendix A contains terms and definitions and Appendix B, the effects of electrical energy on humans. All managers, designers, users, installers, and others who service or operate electrical equipment—including those used for research and development (R&D)—shall comply with these requirements.

More specific information about electrical work can be found in Document 16.2, "Work and Design Controls for Electrical Equipment," and Document 16.3, "LLNL Authority Having Jurisdiction Requirements for Approving Electrical Equipment, Installation, and Work," in the *Environment, Safety, and Health (ES&H) Manual.* In addition, Laboratory programs may consult the Electrical Safety Advisory Board (ESAB) for further guidance on electrical work. The ESAB was chartered on February 20, 1996, and is the Laboratory's technical resource for electrical safety issues. The Board comprises a chair and several members from the Hazards Control Department, Electronics Engineering, Scientific Programs, and Plant Engineering who are knowledgeable in electrical safety. The chair is a member of the Safety Programs Division and is appointed by the Hazards Control Department Head. The other members are nominated by the chair and approved by the Hazards Control Department Head.

2.0 Hazards

Electricity is used in many different ways at LLNL. Each application has its own combination of hazards that includes the potential of electric shock, fire, and burns. Thus, it is essential for all employees, including supplemental labor and subcontractor employees, to be aware of the hazards associated with electrical work and use appropriate protective methods to minimize the risk of an injury or accident.

Appendix B contains more detailed information about the effects of electrical energy on humans.

3.0 Controls for Electrical Work and Electrical Equipment

3.1 General

Only qualified and authorized individuals are permitted to perform electrical work at LLNL. A qualified person is one who has the required skills and knowledge to perform electrical work safely. Such individuals must be aware of the hazards associated with electrical work (see Appendix B for details) and the methods for reducing the risk of electrical accidents that can result from unsafe equipment, adverse environmental conditions, and unsafe acts.

Whenever possible, all circuits or equipment shall be de-energized before beginning any work. Work on energized circuits shall only be performed by authorized workers, as described in Document 16.2. In addition, these workers shall use

- Proper design, fabrication, installation, and documentation techniques.
- Proper operational and maintenance procedures.
- Electrical equipment approved by a nationally recognized testing laboratory (NRTL).
- Proper personal protective equipment (PPE).

In support of Lab-wide electrical safety, management shall take a proactive approach when dealing with the root causes of employees' concerns, near-misses, and incidents or accidents involving electrical hazards.

3.2 Electrical Equipment Conditions of Approval and Use

All electrical equipment, components, and conductors should be listed, labeled, and approved by an NRTL for their intended purpose. Custom-made and installed equipment can be approved for use, by the Electrical Authority Having Jurisdiction (AHJ), if built according to specific standards (e.g., Underwriters Laboratories [UL] 508 or one of the ANSI C series standards). Appropriate documentation for such equipment shall be maintained on file.

When building, repairing, or modifying electrical systems, NRTL-approved equipment must be used if available. Non-NRTL-approved equipment (e.g., shop-made extension cords) shall be built in accordance with an approved design, as specified in Document 16.3.

Document 17.1, "Explosives," in the *ES&H Manual* provides specific guidance for explosives work and for work in explosives areas. Assure an Explosives Safety Engineer has reviewed the process prior to starting work in explosives facilities or areas.

3.3 Work on Electrical Components and Systems

Any live electrical parts shall be positively de-energized when working on or near electrical circuits, equipment, or systems. Circuits and equipment must be considered energized until isolated, locked out and tagged, and verified with an appropriate testing device as described in Document 12.6, "LLNL Lockout/Tagout Program," in the *ES&H Manual*. Where it is possible for the circuits to be energized by another source, or where capacitive and/or inductive devices (including cables) may retain or build up a charge, circuits shall be grounded and shorted. Exceptions to this paragraph may be permitted when the requirements in Document 16.2 are fulfilled.

Additionally, the following precautions shall be observed to improve safety in the workplace:

- Follow LLNL-established procedures (see Table A-1 of Appendix A in Document 16.2.
- Identify and report to your supervisor potential electrical hazards or unexpected occurrences or incidents (i.e., discharges or arcs when applying grounds to circuits thought to be de-energized), including near misses.
- Anticipate potential electrical problems and hazards.
- Do not rush to finish a job; never bypass approved procedures.
- Plan and analyze for safety during each step of any electrical work.
- Keep accurate records (e.g. system one-line drawings, panel schedules, etc.) for electrical or electronic systems.
- Have significant safety-related work (e.g., work requiring an OSP) independently verified.
- Use properly rated test equipment and verify its condition and operation before and after use.
- Know applicable emergency procedures.

3.4 Clearances and Illumination for Electrical Enclosures

A clear working space shall be maintained in the front, back, and on each side of all electrical enclosures and around electrical equipment for safe operation and to permit access for maintenance and alteration. Refer to the documents listed in this section as required. (NOTE: The National Electrical Code (NEC) is available from the Technical

Information Department (TID) Library and the Plant Engineering Library. You may also contact the Hazards Control Department for additional information about the NEC):

- NEC Article 110–26, "Spaces about electrical equipment, (600 volts or less)."
- NEC Article 110–32, "Work space about equipment (over 600 volts)."
- NEC Article 110–33, "Entrance and access to work space."
- NEC Article 110–34, "Work space and guarding (over 600 volts)."
- Document 16.2.

In addition to the NEC, the *IES Lighting Handbook* (latest edition) specifies the following requirements for electrical equipment:

- Adequate illumination shall be provided for all working spaces around electrical equipment.
- The control switches for light circuits shall be positioned away from exposed energized circuits and other potential electrical hazards.

3.5 Temporary Wiring

Construction Power and Lighting. Temporary wiring for electric power and lighting is permitted during periods of construction, remodeling, maintenance, repair, or demolition of equipment or structures and during emergencies. Temporary wiring does not mean a "reduced" level of safety or quality, as this wiring must still conform to certain criteria for electrical work.

Temporary wiring shall have a temporary wiring tag attached to it with the following information:

- Review/approval and signature of the facility manager, area supervisor, lead experimenter, construction inspector, or Plant Engineering Electrician Shop supervisor and the signature of the appropriate ES&H Team industrial safety representative.
- The reason for the temporary wiring (i.e., emergency, construction, test, and/or research and development).
- Installation date.
- Name, phone number, and pager number (if applicable) of the person installing the temporary wiring tag.

In addition, temporary wiring

- Shall be approved or identified as suitable for installation and installed in accordance with the rules prescribed in the current edition of the NEC and 29 CFR 1910 and 1926.
- Shall be protected from accidental damage.
- Shall be removed as soon as the prescribed activity is completed. It shall not be used as a substitute for permanent wiring.
- Shall be color coded in accordance with Plant Engineering or Electronic Engineering standards.
- May be used during an "off-shift working hour" emergency. On the day of installation, a temporary wiring tag shall be completed and attached to the wiring so that it is readily visible. Approvals for the wiring tag must be obtained on the first regular workday after the emergency.

Switches or other means shall be installed to permit the disconnection of all ungrounded conductors of each temporary circuit. All lamps used for temporary illumination shall have a suitable fixture or lamp holder with a guard to prevent damage or accidental contact with energized parts.

Experiments. Temporary wiring may be used for experimental and developmental equipment. There is no time limit on how long the wiring can remain in place, except that it must be removed upon completion of the experiment. Temporary wiring tags are not required for temporary wiring within experimental systems. However, they are required for the power feeder to the power distribution points of experimental systems. The wiring tag on these systems shall contain the same information as previously described.

3.6 Extension Cords/Multiple Outlet Boxes/Flexible Cords and Cables

Extension Cords. Observe the following precautions when using extension cords. Note that extension cords for normal office use do not require a temporary wiring tag.

- Use only three-wire extension cords and cables that conform to the rating, grounding, and non-interchangeability stated in NEC Article 210-7 (Receptacles and Cord Connectors).
- Check extension cords before use to ensure they are adequate for the intended purpose. Plug high-current equipment (e.g., space heaters, hot plates, and coffee pots) directly into a wall receptacle whenever possible.

- Use only one extension cord for lamps, appliances, or other equipment in conjunction with the power supply cord. Laboratory practice prohibits the use of multiple extension cords (daisy chaining) that will increase resistance in an electrical circuit, which in turn will increase heating of conductors, receptacles, and plugs.
- Inspect extension cords for damage before placing them in service and daily during use. Only qualified and authorized persons can repair extension cords; this must be done in a manner approved by the manufacturer. Replace damaged cords with ones listed by an NRTL. Contact the ES&H Team for guidance, if necessary.
- For receptacles connected to circuits with different voltages, frequencies, or current (ac or dc) on the same premises, use a design such that the attachment plugs on the circuits are not interchangeable (see Section 3.7 for details). All extension cords shall be listed or labeled by an NRTL.

Only high-visibility orange or yellow extension cords shall be used outdoors and with portable or integral ground-fault circuit interrupters (GFCIs).

Multiple Outlet Boxes. Observe the following precautions when using multiple outlet boxes:

- Each multiple outlet box shall be plugged into a wall receptacle. Use of one outlet box to provide power to one or more outlet boxes is not permitted.
- Outlet boxes shall not be used to provide power to space heaters, hot plates, coffee pots, or other high-current loads. These types of appliances have caused outlet boxes to burn up.

Note that multiple outlet boxes used in offices, as well as those used to provide surge protection for computers, do not require a temporary wiring tag.

Flexible Cords and Cables. Flexible cords and cables shall comply with the requirements in NEC Article 400 (Flexible Cords and Cables). They shall not be

- Used as a substitute for fixed wiring of a structure.
- Attached to building surfaces.
- Routed through holes in walls, ceilings, or floors; or through doorways, windows, or similar openings.
- Concealed behind building walls, ceilings, or floors.

- Wired with a plug or connector that does not have dead-front construction or strain relief. "Dead-front construction" is defined as electrical equipment built so that it is "without live parts exposed to a person on the operations side of the equipment."
- Placed where they could present a trip or fall hazard.
- Used when the cord insulation is damaged, cracked, or spliced; or when the ground pin is missing from the end of the male cord plug.
- Installed in raceways, except as otherwise permitted by the NEC.

Individual conductors of a flexible cord or cable shall not be smaller than those listed in Table 400-5(A) and (B) of NEC Article 400.

Article 240-4 of the NEC (Protection of Flexible Cords and Fixture Wires) states that flexible cords, including extension cords, shall be protected against overcurrent in accordance with their amperage ratings (see Tables 400-5(A) and 400-5(B)). NEC Article 400-14 states that flexible cords and cables inserted through holes in covers, outlet boxes, or similar enclosures shall be protected by bushings or fittings.

3.7 Power Plugs and Receptacles

The Laboratory uses many different voltages, frequencies, and current (ac or dc) in power systems and equipment. Thus, it is essential to ensure that such equipment cannot be inadvertently connected to the wrong power source. For specific purposes, voltage, and current ratings, use a plug or receptacle that fully complies with the requirements in ANSI C73. See the configuration chart (from ANSI C73) in the NFPA *National Electrical Code Handbook* for information about general-purpose locking and nonlocking plugs and connectors. Use of the National Electrical Manufacturers Association (NEMA) connectors may not be appropriate for all research and development applications. Contact Electronics Engineering Specifications and Standards Group for guidance, if necessary.

3.8 Ground-Fault Circuit Interrupters

Ground-fault circuit interrupters—either circuit breakers or portable ground-fault interrupting receptacles—shall be used for

- All 125-V single-phase, 15-A and 20-A receptacles within 6 feet of a sink or installed outdoors.
- Temporary wiring outdoors.

- Wherever employees will be using electrical equipment around water or in damp environments.

Unlike fuses or standard circuit breakers, which are designed to protect equipment from overcurrent, GFCIs are designed to protect personnel from serious injury or death.

Article 305-6 of the NEC (Ground-Fault Protection for Personnel) requires GFCI protection of all 125 V, single phase, 15, 20, and 30-Amp receptacles that are associated with temporary wiring on construction sites. LLNL requires the use of GFCIs for any type of construction work to ensure personnel protection, even if the receptacle is part of the permanent wiring of the building.

Laboratory practice is to provide its employees and subcontractors with at least the same level of protection from electric shock as they would have in their own homes. NEC Article 210-8 (Ground-Fault Circuit-Interrupter Protection for Personnel) specifies that GFCIs must be installed in the following locations:

- Dwellings where 125-V single-phase, 15-A and 20-A receptacles are installed outdoors.
- Bathrooms, garages, and crawl spaces at or below grade.
- Unfinished basements.
- Where receptacles on countertop surfaces are within 6 ft of a sink.

Thus, all the aforementioned areas within LLNL shall have receptacles with GFCI protection.

Exceptions to these requirements are:

- Laboratory areas where receptacles are required (other than on counter tops) to supply power to specific equipment (i.e., receptacles dedicated to refrigerators or other heavy equipment).
- Line filters and other power supply components in many electronic instruments. These instruments draw sufficient capacitive current to trip a GFCI and therefore are not designed to be connected to GFCI-protected circuits. They also shall not be installed in wet or damp locations.

3.9 Portable Electrical Tools, Equipment, and Instruments

Portable electrical equipment or tools shall always be inspected to identify defects; defective equipment shall be removed from service immediately. Portable electrical equipment shall be connected to a portable GFCI (or a circuit that contains a GFCI) when used outdoors, in damp locations, in any unsafe environment, or for indoor or outdoor construction. Ordinarily, the casings for portable electrical equipment are grounded. If it is necessary to operate this type of equipment with other than a grounded equipment casing, suitable barriers, guards, or shields shall be installed to protect personnel while working on or near the equipment. In addition, a safety procedure shall be written describing the controls for safe operation of the equipment.

Receptacles and flexible cords can be used to connect electrical appliances and equipment (e.g., fans, machine tools, and pumps) to power sources. Receptacles used on a two-wire, single-phase portable generator (or vehicle-mounted generator) with a rating of not more than 5 kW (where the circuit conductors are insulated from the frame and all other grounded surfaces) do not need to be GFCI protected.

3.10 Equipment Grounding

All electrical apparatus, equipment, and systems shall be grounded in accordance with NEC Article 250 (Grounding) and ANSI standards. The conductor used for grounding shall meet the following criteria:

- Be permanent and continuous.
- Facilitate operation of the circuit's protective devices.
- Have sufficiently low impedance to limit the voltage to ground to a safe level at all frequencies and fault-current conditions anticipated.
- Have the capacity (size and rating) to safely conduct any fault current that may be imposed on it for the time required for protective device operation.

Guidelines for proper grounding of programmatic equipment and systems can be found in the Electronics Engineering Department *Grounding Guidelines: Practical Examples for Power Systems at LLNL* (UCID-19752).

3.11 Static Electricity

A static charge is an imbalance of electrons on objects (matter) that can build up on all matter and transfer from one object to another by conduction or induction. The discharge of static electricity can cause shock or a fire or explosion. Although this type of shock is painful, it is not normally physically hazardous and therefore is not considered reportable as an electric shock. It should be noted, however, that injuries may result from reaction to the shock (i.e., by a person rapidly pulling his/her hand away from a metal object and hitting an elbow against a wall or cabinet).

Equipment and Personnel Guidelines. When working with electrical equipment, employees shall follow the guidelines below for their own protection and that of the equipment:

- Grounding of the metal parts or enclosures will continuously discharge static. Therefore, wrist straps and other connections used to ground employees shall be solidly grounded where static-safe workstations are used for semiconductor, electronic, or explosive work. Grounding prevents the wrist strap from becoming a shock hazard in the event of a short circuit from a voltage to the wrist-strap conductor.
- Bonding will equalize the potential between two adjacent noncurrent-carrying metal parts or enclosures. Thus, only approved or listed grounding clamps are acceptable for static bonding and grounding. Alligator clamps are not acceptable.
- Dust is attracted to the face of the video display terminal because of a static charge of approximately 25,000 V. Therefore, never clean the glass face of a computer monitor while the computer is on. When a person touches the screen with a finger, the charge in the portion of the screen touched discharges through the finger with a tiny spark. Electric current does not normally flow through glass, so only the charge on that part of the screen the finger touches is discharged. When cleaning a monitor, however, the entire glass is wet and the charge on the entire screen will discharge to a finger or hand causing a much more painful shock.
- Never allow any electrical-powered office equipment to become wet while it is turned on, and never turn on any electronic equipment when it is wet. Even when a computer is turned off for a few minutes, it is best not to touch the monitor's CRT while handling or using other electronic equipment—including the telephone. Wet or dry, a person may receive an electric shock similar to one that can be received by touching a metallic object when vacuuming, machining a dielectric, or walking across carpeting in leather shoes.

NFPA Regulations for Fire and Lightning. NFPA 77 (Static Electricity) contains requirements for reducing the fire hazard of static electricity. Lightning, an example of static electricity, is covered in NFPA 780 (Lightning Protection Code). This document gives lightning protection requirements for ordinary facilities and for facilities containing flammable vapors, gases, or liquids.

Flammable Vapor. A flammable vapor source can be ignited by static electricity if the following conditions exist simultaneously:

- Generation of a static charge imbalance.

- Static charge accumulation.
- Flammable atmosphere.
- A spark with significant ignition energy or temperature.

Liquids. Electrostatic charges can be generated by the movement of liquid through pipes, funnels, pumps, filters, or by free-flowing through air. Static charges generated by flowing liquids can be reduced or eliminated by bonding or grounding, or both; by lowering the flow rate; or by reducing the amount of misting, spraying, free-fall, and splashing of the liquid. Pay particular attention to situations where the liquid stream may impinge on a connection to a capacitor, high-voltage bushing, or cable terminal. Static charge from the liquid can store hazardous quantities of electrical energy in a capacitor over time. This hazard is most likely to occur when filling electronic apparatus tanks with insulating oil.

3.12 Personal Protective Equipment

Personal protective equipment is required when installing, examining, adjusting, servicing, fabricating, testing, or maintaining electrical equipment. The work supervisor shall provide employees with the appropriate PPE, and shall ensure that the equipment is used properly. Alternatively, employees may contact the area ES&H Team for assistance in selecting the appropriate PPE for the operation. Protective footwear; hard hats; and insulated, nonmetallic-framed safety glasses shall meet the requirements of ANSI Z41, ANSI Z87.1, and ANSI Z89.2 (see Table 1 below).

Rubber-insulated (nonconductive) protective equipment shall be visually inspected at the beginning of each workday before use and after performing work that can cause damage to PPE. This inspection shall include an air test of the gloves used. Hot sticks, grounds, aerial-lift equipment and booms, hot rope, and hot ladders shall also be visually inspected.

3.13 Reviews and Inspections

Major modifications to new and existing facilities and projects may be inspected by the DOE (or authorized designee) to verify compliance with codes and standards in effect on the day that such work is approved by a final design review. If the modification involves a hazard to life, equipment, or property, current safety requirements shall be reviewed and used to mitigate the hazard.

Table 1. ASTM/ANSI standards for PPE.

Protective equipment or apparel	ASTM standard	ANSI standard
Rubber, insulating gloves	D 120	—
Rubber, insulating matting	D 178	—
Rubber, insulating blankets	D 1048	—
Rubber, insulating covers	D 1049	—
Rubber, insulating line hose	D 1050	—
Rubber, insulating sleeves	D 1051	—
Protective foot wear	—	Z41
Eye and face protection	—	Z87.1
Nonconductive hard hats (helmets)	—	Z89.2
Leather protectors for rubber insulating gloves	F 696	—

3.14 Emergency Assistance and Rescue

Anyone who witnesses or discovers a serious electric shock that results in any of the conditions listed below, at the Livermore site or at Site 300 shall immediately call the Fire Department Emergency Rescue (dial 911) (from a cell-phone, call 925-447-6880).

1. Obvious serious injury (e.g., loss of consciousness, significant trauma).
2. Altered mental status (e.g., confusion, slow/slurred speech).
3. Other obvious injury (e.g., laceration, muscle strain, burn).

In addition to calling 911:

- Ensure that all potential sources of energy are safe and in a neutral state, if you are qualified.
- Initiate cardiopulmonary resuscitation (CPR), if appropriate. (Only trained personnel should perform this task.)
- Notify the victim's supervisor and the appropriate ES&H Team as soon as possible. (The victim's supervisor and the Hazards Control Department will want to determine what caused the electric shock.)

Refer to Document 10.1, "Occupational Medical Program," in the *ES&H Manual* for additional information.

3.15 Minor Shocks

All other electric shock victims must be taken to the Health Services Department for evaluation so that potentially damaging effects can be detected early and treated properly. It should be noted that such effects may not be immediately recognized and can appear later (see Appendix B for details). Do not let the shock victim drive himself to the Health Services Department.

- Notify the victim's supervisor and the appropriate ES&H Team as soon as possible. (The victim's supervisor and the Hazards Control Department will want to determine what caused the electric shock.)

3.16 Analysis of Electrical Incidents

Serious and potentially lethal incidents, including near misses that could result in a serious or potentially lethal shock, shall undergo an incident analysis in accordance with Document 4.5, "Incidents—Notification, Analysis, and Reporting," in the *ES&H Manual*. This analysis shall be determined by facility or program management and the responsible ES&H Team.

- Properly secure the area once the victim is under care, leaving items and equipment in the same position as much as possible. Try to remember the original position of items that may have been moved during response to the accident.
- Record the time, date, and location of the accident; the name of the victim and any witnesses; who was notified; the voltage and current; the contact parts of the body; what equipment or system was being serviced; and the shock reaction and duration of the shock.

3.17 Specific Training

Electrical Workers. Employees who perform electrical work shall be trained to recognize the hazards associated with their work environment and use appropriate procedures and protective equipment to minimize the risk of an accident or injury. The payroll supervisor provides trained electrical workers. Work supervisors shall verify the qualifications and training of all electrical workers before they are permitted to perform electrical work. Training requirements are identified in Document 40.1, "LLNL Training Program Manual," in the *ES&H Manual* and the Directorate Training Implementation Plan.

Employee training shall be documented with respect to the specific equipment and tasks for which the employee is qualified. Much of the experience required for an employee to be considered qualified is specific to the equipment and tasks involved.

On-the-job training is always a necessary component of a qualification program. Classroom training, including courses offered by the Hazards Control Department, is a useful way to ensure that employees share a common level of basic knowledge on which to build specific on-the-job training. Additionally, employees can gain knowledge and experience about how to perform their jobs safely and properly by taking courses offered by universities and trade schools or through apprenticeships, on-the-job training (OJT), or other formalized training. The depth of training and how training is provided shall be determined by the hazards associated with the employee's respective tasks.

Electrical workers shall be trained in and familiar with the following subject areas:

- The safety-related work practices required by 29 CFR 1910, Subparts J and S; and 29 CFR 1926, Subparts K and V (see Sections 5.0 and 6.3 for details).
- Techniques necessary to de-energize electrical systems, identify live parts of equipment, and determine the nominal voltage of exposed live parts and clearance distances specified in Document 16.2.
- Procedures for locking out and tagging energized electrical circuits and equipment safely. Document 12.6 contains specific details.
- Other subjects, such as
  - — Electrical Safety Requirements for Employee Workplaces (NFPA 70E).
  - — National Electrical Code (NFPA 70).
  - — National Electrical Safety Code (ANSI/IEEE C2).
  - — Use of personal protective grounds (29 CFR 1926.954(e)).
  - — Use of testing and measuring equipment (29 CFR 1910.334(c)).
  - — Safety plans and work authorization documents (IWS, FSPs and OSPs).
  - — Use and care of personal protective equipment (29 CFR 1910.335(a)).
  - — Hazard categories and personnel requirements.
  - — The requirements of this document.

The Hazards Control Department offers the following courses to fulfill some of these requirements:

- HS5210, "Capacitor Safety Orientation."
- HS5230, "High-Voltage Safety."
- HS5245, "Lock and Tag Procedure."
- HS5250, "Working on Energized R&D Equipment."

Refresher training for electrical workers is required at intervals listed in the course catalog, and shall include a formal review of current regulations and safety practices.

Electrical workers should take HS1620, "Multimedia First Aid with CPR."

Nonelectrical Workers. The Occupational Safety and Health Administration requires training for nonelectrical workers whose job assignments require them to be close to exposed parts of electrical circuits operating at 50 V or more. The Hazards Control Department offers the following course for this purpose:

- HS5220, "Electrical Hazards Awareness."

3.18 Supplementary Training

In addition to the courses the Hazards Control Department offers, both electrical and nonelectrical workers whose job assignment requires them to work close to exposed electrical circuits operating at 50 V or more to ground (in accordance 29 CFR 1910.332) should receive supplementary training in the following subject areas:

- The proper handling of portable tools and appliance cords.
- Procedures for resetting overcurrent protective devices.
- Techniques for approaching distances to overhead conductors.
- The meaning of electrical safety warnings and barriers.
- Electrical hazards associated with water.
- The proper response to electric shock.

For additional training requirements, see the LLNL *Training Program Manual* and the Directorate Training Implementation Plan.

4.0 Responsibilities

All workers and organizations shall refer to Document 2.1, "Laboratory and ES&H Policies, General Worker Responsibilities, and Integrated Safety Management," in the *ES&H Manual* for a list of general responsibilities. This section describes specific responsibilities of LLNL organizations and workers who have key safety roles. The responsibilities of individuals with regard to electrical work are listed below each title.

4.1 Employees

- Only perform the tasks for which you are qualified.
- Understand the basic principles of electricity and electrical safety.
- Follow applicable OSHA requirements.

- Use the proper tools and required PPE.
- Request additional training to avoid working beyond your level of qualification or comfort.
- Comply with the requirements set forth by the DOE, OSHA, and LLNL.

4.2 Work Supervisors

- Ensure employees
  - — Comply with the requirements set forth by the DOE, OSHA, LLNL, and other regulatory agencies.
  - — Have the appropriate PPE available and use them properly.
  - — Are adequately qualified to perform their jobs.
- Determine the work each employee is qualified to perform and make work assignments accordingly.

4.3 Electrical Safety Advisory Board

- Provide support primarily through the ES&H Teams, which are the initial point-of-contact for all safety issues raised by Programs or individuals.
- Identify electrical safety hazards and make recommendations for resolution.
- Provide support to program line management responsible for analyzing electrical accidents and incidents.
- Evaluate electrical accidents and incidents to determine trends.
- Develop, review, and approve electrical safety training programs.
- Interact on a continual basis with groups (e.g., ES&H Working Group and subcommittees, Directorate safety committees and councils, the ES&H Teams) charged with providing a safe work environment for employees. This interaction may include conducting electrical safety presentations and providing a forum (e.g., written or electronic communication or meetings) for the exchange of ideas and information.
- Inform management and employees of lessons learned from electrical accidents and incidents.
- Participate in DOE electrical safety programs (e.g., DOE and EFCOG Electrical Safety Committees).

5.0 Work Standards

29 CFR 1910, Subpart S, "Electrical."

29 CFR 1910, Subpart H, "Hazardous Materials."

29 CFR 1910, Subpart J, "General Environmental Controls." (Section 1910.147, "The control of hazardous energy lockout/tagout," specifically applies.)

29 CFR 1910, Subpart R, "Special Industries." (Section 1910.269, "Electrical power transmission, and distribution," specifically applies.)

29 CFR 1910, Subpart I, "Personal Protective Equipment."

29 CFR 1926, Subpart K, "Electrical."

DOE M 440.1-1, *DOE Explosives Safety Manual* .

NFPA 70, *National Electrical Code*.

6.0 Resources for More Information

6.1 Contacts

For additional information about the topics covered this document, contact the following:

- Work supervisor—General electrical concerns.
- Area ES&H Team industrial safety engineer—Specific concerns about electrical safety.
- Industrial Safety/Safety Programs Division—Institutional electrical safety concerns.
- Safety Training.

6.2 Lessons Learned

For lessons learned specific to electrical work areas or electrical equipment, refer to the following web site:

http://www.llnl.gov/llnl_only/es_and_h/lessons/lessons.shtml

6.3 Other Sources

29 CFR 1910.268, "Telecommunications."

29 CFR 1926, Subpart V, "Power Transmission and Distribution" (latest edition).

ANSI C73, "American National Standard on Dimensions of Attachment Plugs" [configuration tables for general-purpose nonlocking and locking plugs and receptacles].

ANSI C84.1, "For Electric Power Systems and Equipment—Voltage Ratings (60 Hz)."

ANSI/IEEE Standard 18, "IEEE Standard for Shunt Power Capacitors."

ANSI/IEEE 80, "IEEE Guide for Safety in AC Substation Grounding."

ANSI/IEEE C2, "National Electrical Safety Code" (latest edition)."

ANSI/ISA-S82.01, .02, and .03, "Safety Standard for Electrical and Electronic Test, Measuring, Controlling and Related Equipment."

ANSI Z136.1, Section 7, "ANSI Standard for the Safe Use of Lasers" [Subsection 7.4, "Electrical Hazards."]

Charles F. Dalziel, "The Effects of Electric Shock on Man," *Industrial Radio Engineers Transactions on Medical Electronics* (May 1956).

DOE/EV/0051/1, *Electrical Safety Requirements for R&D Activities*.

DOE-HDBK-1092-98, *Electrical Safety Handbook*.

Electronics Engineering Department, *Grounding Guidelines: Practical Examples for Power Systems at* LLNL, Lawrence Livermore National Laboratory, Livermore, CA (UCID-19752).

FIPS PUB 94, "Guideline on Electrical Power for Automatic Data Processing Installations."

IEEE 450-IEEE, "Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations."

Illuminating Engineering Society, *IES Lighting Handbook* (latest edition).

NETA, International Electrical Testing Association, Inc., "Acceptance Testing Specifications for Electric Power Distribution Equipment and Systems."

NFPA 70B, *Electrical Equipment Maintenance*.

NFPA 70E, *Electrical Safety Requirements for Employee Workplaces* (latest edition).

NFPA 75, *Electronic Computer/Data Processing Equipment*.

NFPA 77, *Recommended Practice on Static Electricity*.

NFPA 780, *Lightning Protection Code* (latest edition).

NFPA 79, *Electrical Standard for Industrial Machinery National Fire Protection Association* (interpretations of current NFPA 70).

NFPA 110, *A-Stored Electrical Energy Emergency and Standby Power Systems*."

Ralph H. Lee, "Human Electrical Sheet" while an IEEE Fellow at E. I. duPont de Nemours & Co.; and "Electrical Safety in Industrial Plants," in *IEEE Spectrum*, June 1971.

Appendix A

Terms and Definitions

The following terms and acronyms are used in this document and the supporting appendices.

Affected employee	Any employee (including subcontractors) whose job requires him/her to operate or use a machine or work in an area where service or maintenance of equipment is being performed.
ac	Alternating current.
ANSI	American National Standards Institute.
Authority having jurisdiction (AHJ)	An individual who interprets the requirements of all electrical codes and standards such as the National Electrical Code (NFPA 70); the National Electrical Safety Code (ANSI/IEEE C2); 29 CFR 1910, Subpart S; 29 CFR 1926, Subparts K and V; and Document 16.3. This individual also approves electrical equipment, wiring methods, electrical installations, and utilization of equipment for compliance.
Authorized person	Any employee (including subcontractors) with acquired skills and training who has been approved or assigned by the supervisor to perform specific work or tasks.
Bonding	The permanent joining of metallic parts to form an electrically conductive path that will ensure electrical continuity and the capacity to conduct safely any current likely to be imposed.
CFR	Code of Federal Regulations.
Competent person	A person who is (1) capable of identifying existing and predictable hazards in workplaces; and (2) authorized and qualified by management to take prompt corrective measures to eliminate hazards, provide first aid, and notify the appropriate personnel when an accident or incident occurs.
CPR	Cardiopulmonary resuscitation.

Dead-front construction	Electrical equipment built so that, in NEC 70 Article 100's definition, it is "without live parts exposed to a person on the operating side of the equipment." Article 384 (Switchboards and Panel Boards), in paragraph 384-3.(a), requires that "barriers shall be placed in all service switchboards that will isolate the service bussbars and terminals from the remainder of the switchboard."
dc	Direct current.
Electrical equipment	A general term for material, fittings, devices, appliances, fixtures, apparatus, and the like that are used as a part of or in connection with an electrical installation. The term applies to both power-generation equipment and electronics equipment.
Electrical hazard	Any situation in which an employee or any conductive tool or object in contact with the employee could contact or approach closer than the safe clearance distance of any live part or other energized conductor. Any situation in which electrical equipment is likely to cause a fire because of defective components or design. Examples of electrical hazards include inadequate working clearance while working on energized circuits, exposed energized parts, electrical equipment inadequately guarded or enclosed, electrical equipment in an unsafe environment, and unsafe electrical equipment. Generally, electrical equipment that is not in compliance with OSHA regulations or NEC standards presents a potential hazard.
Electrical worker	An electrical worker is a person trained, qualified, and authorized to work on electrical equipment. He/she is usually hired specifically for this purpose.
Facility power	Main disconnects, panel boards, switches, and associated wiring are considered facility/building power and are typically less than 600 V ac. These systems are designed and installed to operate facilities in these buildings (i.e., lighting, heating, air conditioning, or standby power supply and circuitry).
FSP	Facility Safety Plan.
GFCI	Ground-fault circuit interrupter.

Grounded	Connected to earth or to some conducting body that serves in place of the earth. Physically and intentionally connected to the earth through a ground connection of sufficient low impedance and with sufficient current-carrying capacity to prevent the buildup of voltages that may result in undue hazard to connected equipment or persons. (See ungrounded.)
Joule (J)	Watt-second (power × time); a unit of energy.
Labeled	Equipment or materials to which a label, symbol, or other identifying mark has been applied by an NRTL.
Listed	Equipment or materials included in a list published by an NRTL.
Live/energized parts	The current edition of 29 CFR 1910 defines a "live part" as an electrically conducting part carrying more that 50 V ac or dc. (A part may be designated as "not live" if the current from the part to ground through 1500 Ω non-inductive resistance shunted by a capacitance of 0.15 μf cannot exceed 0.5 mA, even though the part carries voltage equal to or greater than that specified for a live part.)
Lockout and tag procedure	LLNL's general procedure for affixing appropriate locks and tags to energy-isolating devices to prevent inadvertent energizing or start-up of machines or equipment while service and maintenance is being performed. Lockout devices prevent the release of energy that could cause injury or death. Refer to Document 12.6 for details on this procedure.
Minimum work distance or clearance	A minimum separation distance between a qualified electrical worker (or any conducting object touching the worker) and any energized component. Also, a mandatory separation distance between any energized component and vehicles or machinery. See Document 16.2, 29 CFR 1910.303, and 29 CFR 1910.304.
NEC	National Electrical Code.
NEMA	National Electrical Manufacturers Association.
NFPA	National Fire Protection Association.

Nationally recognized testing Laboratory (NRTL)	An organization that is concerned with product evaluation and maintains periodic inspection of listed equipment and materials. The NRTL ensures that the equipment or materials meet appropriate designated standards and that they have been tested and found to be suitable for use in a specified manner. (Refer to 29 CFR 1910.7, "Definition and Requirements for a Nationally Recognized Testing Laboratory.")
Nominal system voltage	A nominal value assigned to a circuit or system to conveniently designate its voltage class (e.g., 120/240 V, 480Y/277 V, 600 V). The actual voltage at which a circuit operates can vary from the nominal within a range that permits satisfactory operation of the equipment. (Refer to ANSI C84.1, "Electric Power Systems and Equipment—Voltage Ratings [60 Hz]" for details.)
OJT	On-the-job training.
OSHA	Occupational Safety and Health Administration.
OSP	Operational Safety Plan.
PPE	Personal protective equipment.
Qualified person	A person who has been determined by his/her supervisor to have the skills, knowledge, and abilities to safely perform the work to which he/she is assigned. Qualifications may include a recognized degree, certificate, or professional standing—through extensive knowledge, training, and experience—or that one has successfully demonstrated the ability to resolve problems relating to the subject matter or work to the satisfaction of his/her supervisor.
Safety watch	A person specifically assigned to stand by (within visible and audible range of workers) and continually monitor equipment and personnel for safety.
Strain relief	A mechanical device that prevents force from being transmitted to the connections or terminals of a cable.

Temporary wiring — Electrical wiring that is temporarily installed for a limited time to complete a specific task (e.g., construction of a new facility or performance of R&D work). Temporary wiring methods must apply sound engineering practices to ensure adequate electrical safety of temporary wiring installations. Temporary wiring shall conform to the requirements in Section 3.5 of this document, Article 305 of the NEC, and the respective subparts of 29 CFR 1910 and 29 CFR 1926.

Ungrounded — A condition having no physical connection or continuity with earth ground. A condition of insulation or isolation. (See grounded.)

Utility power — Utility, transmission, and distribution of electrical power systems typically above 600 V ac (i.e., substations, vaults, transformers, switch gear) prior to the final point of transformation and distribution. These electrical systems and equipment then furnish electrical power to buildings and facilities through an electric service entrance. Qualified Plant Engineering personnel (or their designees) are the *only* individuals authorized to work on these high-voltage systems.

Work supervisor — The person responsible for supervising and directing the work and ensuring the health and safety of workers. Specific responsibilities include

- Understanding potential hazards of the work.
- Ensuring that an employee is qualified by knowledge, training, and experience; that he/she has successfully demonstrated the ability to safely complete the work; and that the employee is authorized to perform the work.
- Having a complete understanding and the ability to reach agreement with the qualified person about the work to be performed, the sequence in which it should be done, and the potential and present hazards involved—having outlined those hazards and/or limitations of tasks to the extent considered necessary to ensure the worker's health and safety.

Appendix B

Effects of Electrical Energy on Humans

B.1 Physiological Effects

Electricity flowing through the human body can shock, cause involuntary muscle reaction, paralyze muscles, burn tissues and organs, or kill. The typical effects of various electric currents flowing through the body on the average 150-lb male and 115-lb female body are given in Table B-1.

Burns. Although a current may not pass through vital organs or nerve centers, internal electrical burns can still occur. These burns, which are a result of heat generated by current flowing in tissues, can be either at the skin surface or in deeper layers (muscles, bones, etc.), or both. Typically, tissues damaged from this type of electrical burn heal slowly.

Burns caused by electric arcs are similar to burns from high-temperature sources. The temperature of an electric arc, which is in the range of 4,000–35,000°F, can melt all known materials, vaporize metal in close proximity, and burn flesh and ignite clothing at distances up to 10 ft from the arc.

Table B-1. Effects of electric current on the human body (Ref. 1).

	Direct current		Alternating current (mA)				
	(mA)		60 Hz		10,000 Hz		
Effect/feeling	150 lb	115 lb	150 lb	115 lb	150 lb	115 lb	Incident severity
Slight sensation	1	0.6	0.4	0.3	7	5	None
Perception threshold	5.2	3.5	1.1	0.7	12	8	None
Shock not painful	9	6	1.8	1.2	17	11	None
Shock painful	62	41	9	6	55	37	Spasm, indirect injury
Muscle clamps source	76	51	16	10.5	75	50	Possibly fatal
Respiratory arrest	170	109	30	19	180	95	Frequently fatal
≥0.03-s vent. fibril.	1300	870	1000	670	1100	740	Probably fatal
≥3-s vent. fibril.	500	370	100	67	500	340	Probably fatal
≥5-s vent. fibril.	375	250	75	50	375	250	Probably fatal
Cardiac arrest	—	—	4000	4000	—	—	Possibly fatal
Organs burn	—	—	5000	5000	—	—	Fatal if it is a vital organ

Delayed Effects. Damage to internal tissues may not be apparent immediately after contact with the current. Internal tissue swelling and edema are also possible.

Critical Path. The critical path of electricity through the body is through the chest cavity. At levels noted in Table B-1, current flowing from one hand to the other, from a hand to the opposite foot, or from the head to either foot will pass through the chest cavity paralyzing the respiratory or heart muscles, initiating ventricular fibrillation and/or burning vital organs.

B.2 Biological Effects of Electrical Hazards

Influential Variables. The effects of electric current on the human body can vary depending on the following:

- Source characteristics (current, frequency, and voltage of all electric energy sources).
- Body impedance and the current's pathway through the body.
- How environmental conditions affect the body's contact resistance.
- Duration of the contact.

Source Characteristics. An alternating current (ac) with a voltage potential greater than 550 V can puncture the skin and result in immediate contact with the inner body resistance. A 110-V shock may or may not result in a dangerous current, depending on the circuit path which may include the skin resistance. A shock greater than 600 V will always result in very dangerous current levels. The most severe result of an electrical shock is death.

Conditions for a serious (potentially lethal) shock across a critical path, such as the heart, are

1. More than 30-V root mean square (rms), 42.4-V peak, or 60 V dc at a total impedance of less than 5000 Ω.
2. 10 to 75 mA.
3. More than 10 J.

Conditions for a potentially lethal shock across the heart are

1. More than 375 V at a total body impedance of less than 5000 Ω.
2. More than 75 mA.
3. More than 50 J.

The worst possible frequency for humans is 60 Hz, which is commonly used in utility power systems. Humans are about five times more sensitive to 60-Hz alternating current than to direct current. At 60 Hz, humans are more than six times as sensitive to alternating current than at 5000 Hz—and the sensitivity appears to decrease still further as the frequency increases. Above 100–200 kHz, sensations change from tingling to warmth, although serious burns can occur from higher radio-frequency energy.

At much higher frequencies (e.g., above 1 MHz), the body again becomes sensitive to the effects of an alternating electric current, and contact with a conductor is no longer necessary; energy is transferred to the body by means of electromagnetic radiation (EMR). For a discussion on the effects of EMR and the controls required for these sources, refer to Document 20.7, "Nonionizing Radiation and Fields (Electromagnetic Fields and Radiation with Frequencies Below 300 GHz," in the *ES&H Manual*.

Body Impedance. Three components constitute body impedance: internal body resistance and the two skin resistances at the contact points with two surfaces of different voltage potential. One-hand (or single-point) body contact with electrical circuits or equipment will prevent a person from completing a circuit between two surfaces of different voltage potential. Table B-2 provides a listing of skin-contact resistances encountered under various conditions. It also shows the work area surfaces and wearing apparel effects on the total resistance from the electrical power source to ground. This table can be used to determine how electrical hazards could affect a worker in varying situations.

Table B-2. Human resistance (Q) for various skin-contact conditions (Ref. 2).

Body contact condition	Dry (Ω)	Wet (Ω)
Finger touch	40,000–1,000,000	4,000–15,000
Hand holding wire	15,000–50,000	3000–5000
Finger-thumb grasp	10,000–30,000	2000–5000
Hand holding a pliers	5,000–10,000	1000–3000
Palm touch	3000–8000	1000–2000
Hand around 1.5-in. pipe or drill handle	1000–3000	500–1500
Two hands around 1.5-in. pipe	500–1500	250–750
Hand immersed	—	200–500
Foot immersed	—	100–300

Life-Threatening Effects. Charles F. Dalziel,[1] Ralph H. Lee,[2] and others have established the following criteria for the lethal effects of electric shock:

- Currents in excess of a human's "let-go" current (≥16 mA at 60 Hz) passing through the chest can produce collapse, unconsciousness, asphyxia, and even death (see also Table B-1).
- Currents (≥30 mA at 60 Hz) flowing through the nerve centers that control breathing can produce respiratory inhibition, which could last long after interruption of the current.
- Cardiac arrest can be caused by a current greater than or equal to 1 A at 60 Hz flowing in the region of the heart.
- Relatively high currents (0.25–1 A) can produce fatal damage to the central nervous system.
- Currents greater than 5 A can produce deep body and organ burns, substantially raise body temperature, and cause immediate death.
- Delayed reactions and even death can be caused by serious burns or other complications.

The most dangerous current flow via the chest cavity is through the heart when the shock occurs in the time relative to the normal heart rhythm. This current may cause ventricular fibrillation, which is defined as repeated, rapid, uncoordinated contractions of the heart ventricles. Ventricular fibrillation that alters the heart's normal rhythmic pumping action can be initiated by a current flow of 75 mA or greater for 5 seconds (5-s) or more through the chest cavity.

Probability of Ventricular Fibrillation. To determine the 5-s current flow (in mA) necessary to cause a 0.5% probability of ventricular-fibrillation, multiply a person's weight (in lb) by 0.49. To determine the 5-s current flow (in mA) necessary to cause a 99.5% probability of ventricular fibrillation, multiply a person's weight (in lb) by 1.47.

B.3 Determining How Much Current Is Passing Through a Body

Use the information in Tables B-l through B-3 to project how electrical hazards could affect a worker in varying situations when protective equipment and apparel are in series with current flowing through a body. To determine how much current, I, is passing along a body path, use the formula I = E/R. The voltage, E, can be obtained using an appropriate voltmeter. The total body resistance, R, can be determined by combining the appropriate resistance from Table B-2 with that from Table B-3.

Table B-3. Resistance values for equal areas (130 cm^2) of various work area materials (Ref. 2).

Material	Resistance (Q)
Rubber gloves or soles	2.0×10^7
Dry concrete above grade	1.0×10^6 to 5.0×10^6
Dry concrete on grade	2.0×10^5 to 1.0×10^6
Leather sole, dry, including foot	1.0×10^5 to 5.0×10^5
Leather sole, damp, including foot	5.0×10^3 to 2.0×10^4
Wet concrete on grade	1.0×10^3 to 5.0×10^3

References

1. Charles F. Dalziel, "The Effects of Electric Shock on Man," *Industrial Radio Engineers Transactions on Medical Electronics* (May 1956).
2. Ralph H. Lee, "Human Electrical Sheet" while an IEEE Fellow at E. I. duPont de Nemours & Co.; and "Electrical Safety in Industrial Plants," in *IEEE Spectrum*, June 1971.